

State-of-the-Art Technologies for Stationary Natural Gas Engines

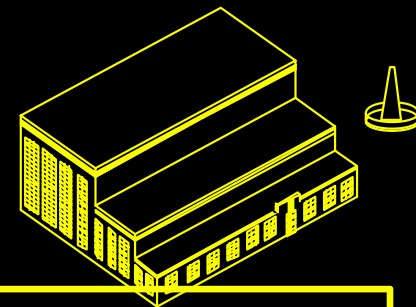
Bryan Willson
Research Director



California ARICE Workshop, Sacramento

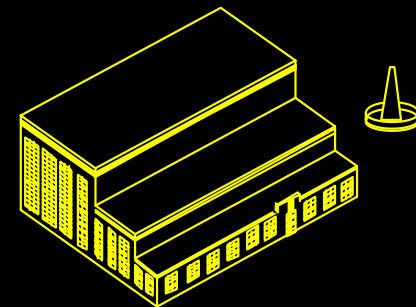
July 10, 2001

NOx Emissions from Power Generation Options



	lb NOx / MW-hr
Typical mix of California gas-fired power plants	0.5
New natural gas peaking turbine	0.1 – 0.8
Existing Diesel Standby Generators	25 – 30
Diesel Engine w/ Best Available Control	7
Dual-fuel natural gas IC generator	1.0 -2.5
Current lean-burn natural gas engine	1.25
Advanced natural gas IC generator	0.7
DOE Advanced Natural Gas Reciprocating Engine targets	0.07

The Role of Natural Gas Engines



US: 8,000 slow speed natural gas engines produce over 60 billion kW-hr of power for natural gas transmission each year

California: 2,500¹-15,000³ medium-speed natural gas engines

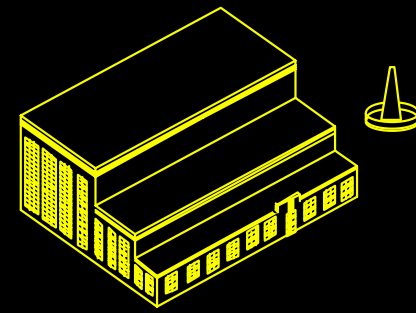
California: 2,600¹-16,000² medium-speed diesel engines
– could be converted to natural gas using dual-fuel technology

¹CARB Oct 2000 BACT/RACT proposal reports 2,596 diesel engines & 2,478 natural gas engines

²based on CARB Diesel Risk Reduction Plan, believed to be significantly low

³based on CARB Diesel Risk Plan inventory and April 2001 CARB BACT/RACT determination that there were roughly equal numbers of stationary diesel and natural gas engines.

Outline



- Current gas engine research
- Prognosis for dual-fuel diesel / natural gas engines

Presentation focuses on large bore natural gas engines since this has been one of the most active areas of gas engine research over past decade

Significant application of large-bore work to medium-speed engines



2-stroke lean burn gas engine
Cooper-Bessemer GMV-4

Large Engines at the EECL



4-stroke lean burn gas engine
Waukesha 3521

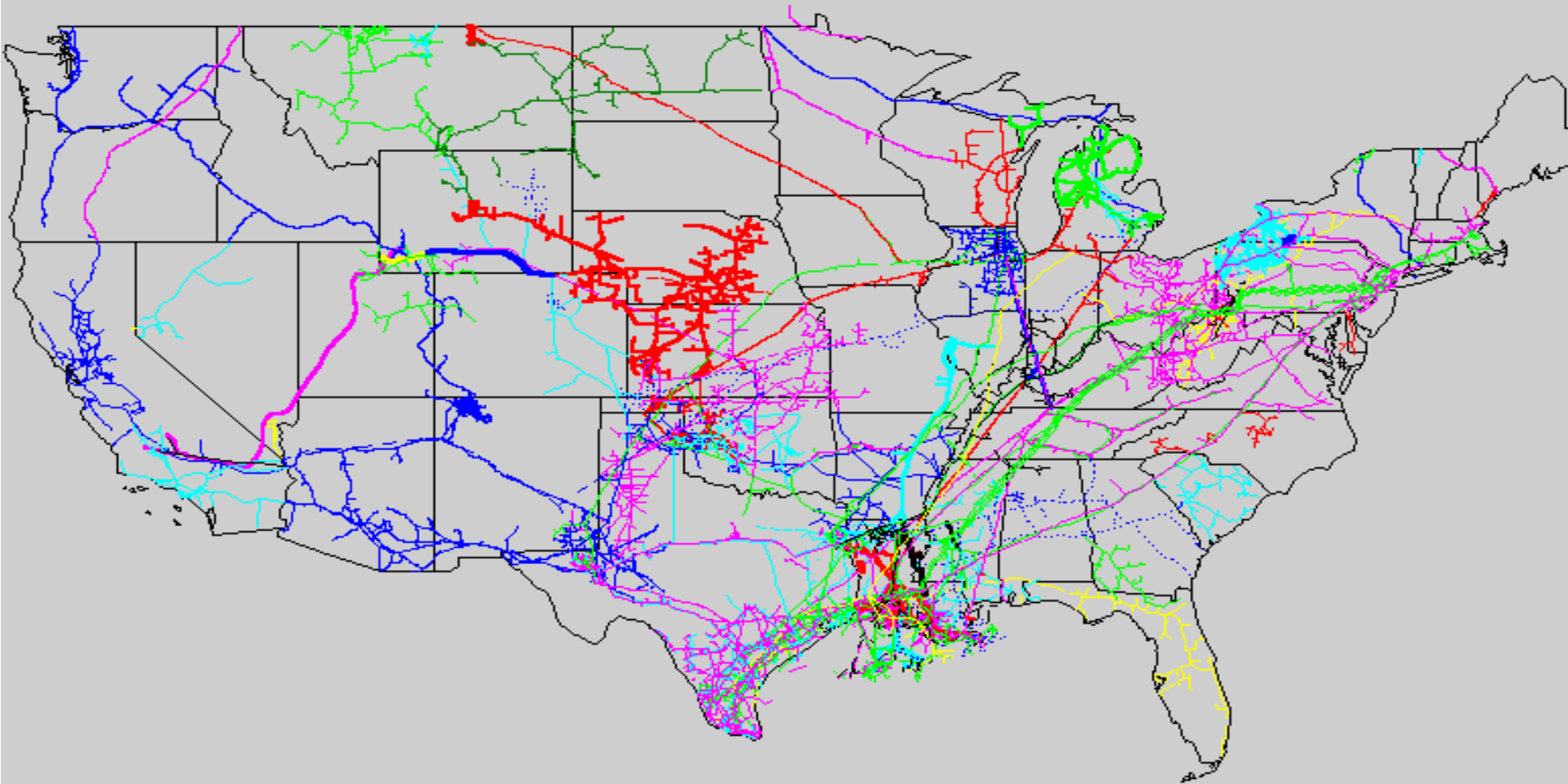
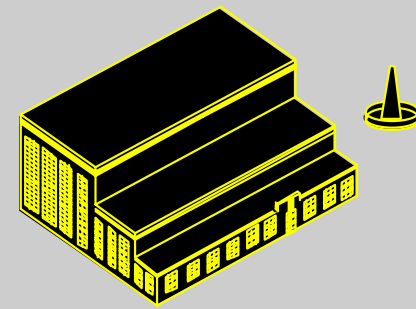


4-stroke diesel engine
Caterpillar 3508 - uninstalled

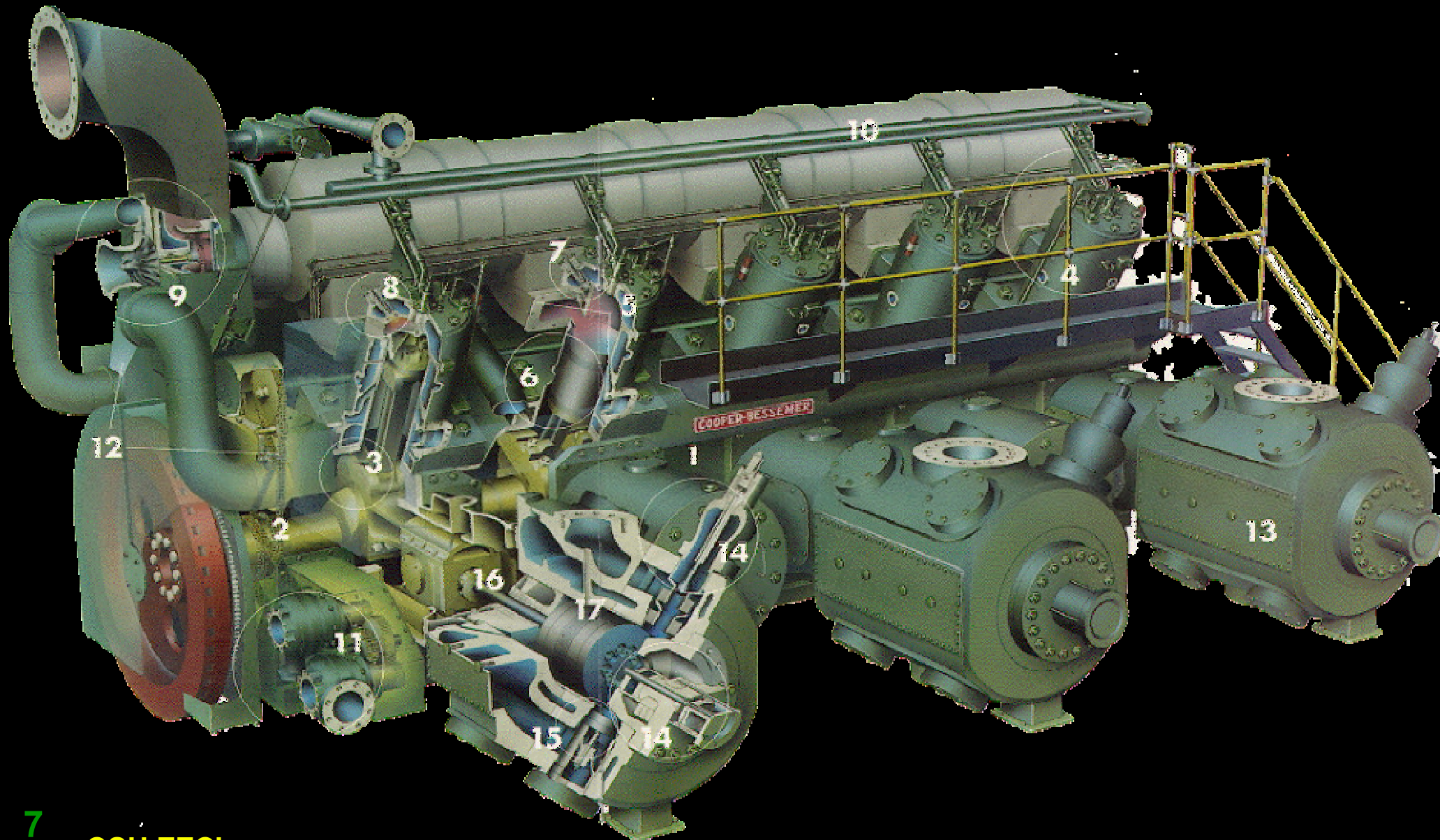
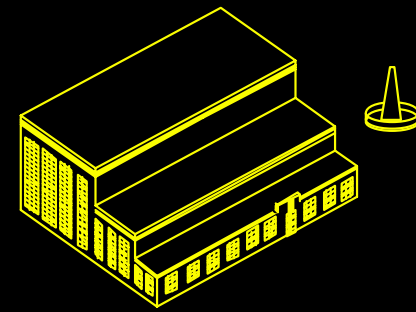


4-stroke rich burn gas engine
Superior 6G-825

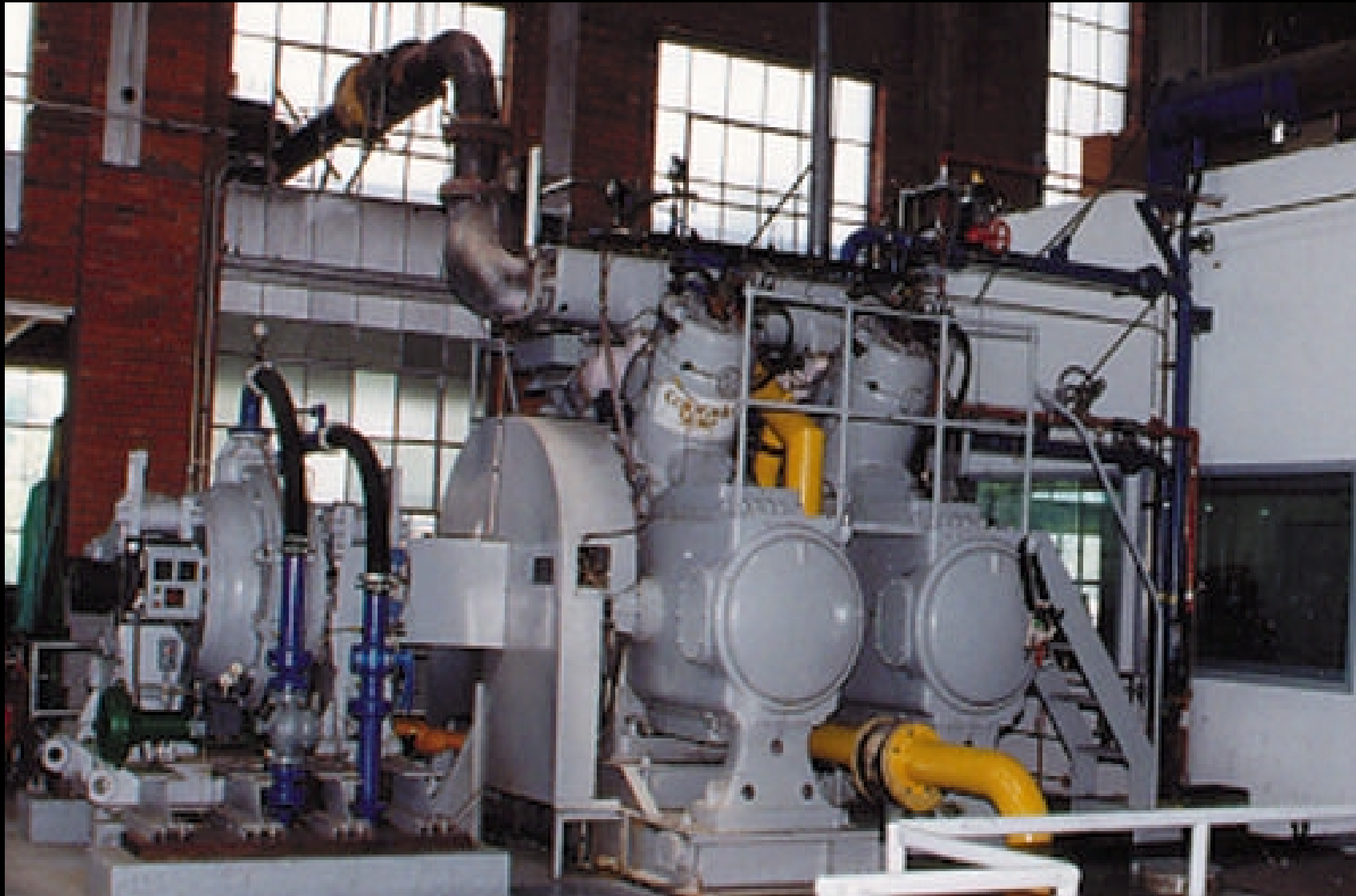
US Natural Gas Pipeline System



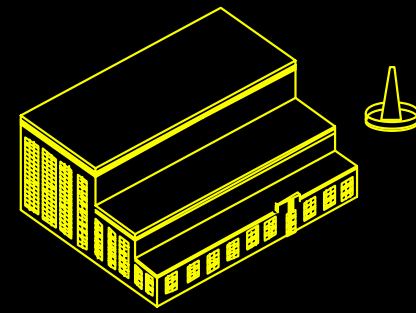
Typical 2-Stroke Gas Compression Engine



Large Bore Engine Testbed Funded by Pipeline Research Council International & GTI



Research Focus



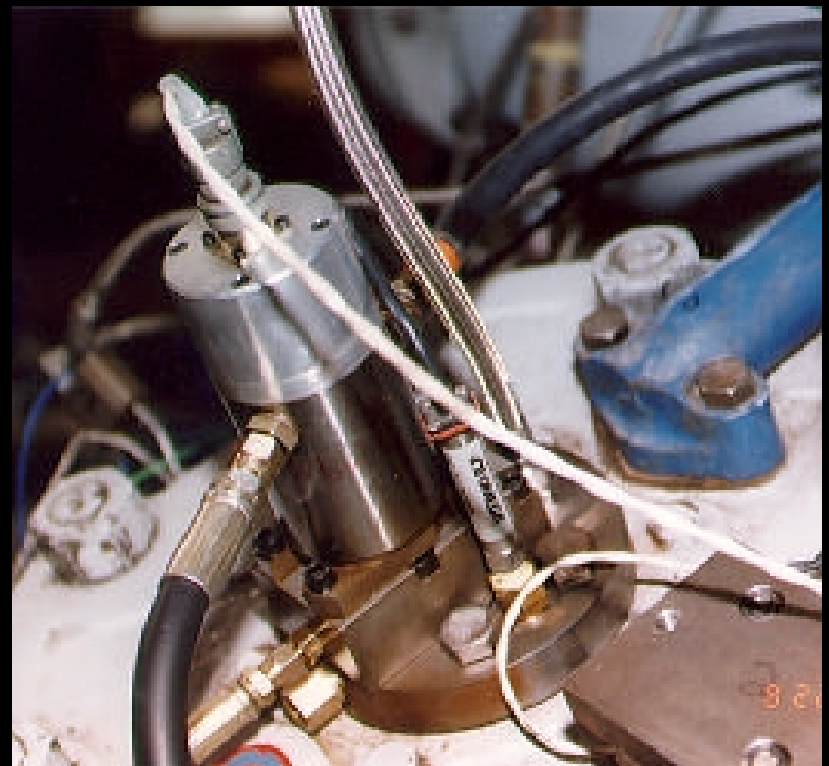
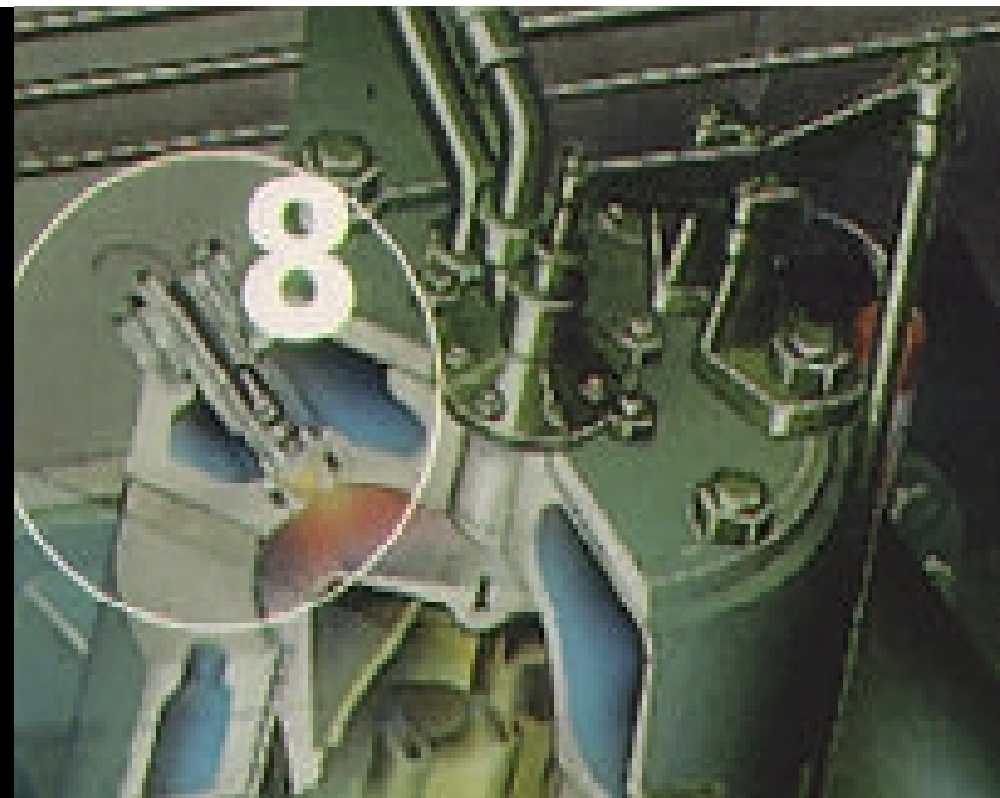
- Enhanced mixing
- NO_x / HAPs research
- Advanced ignition systems

“Low Pressure” Gas Admission

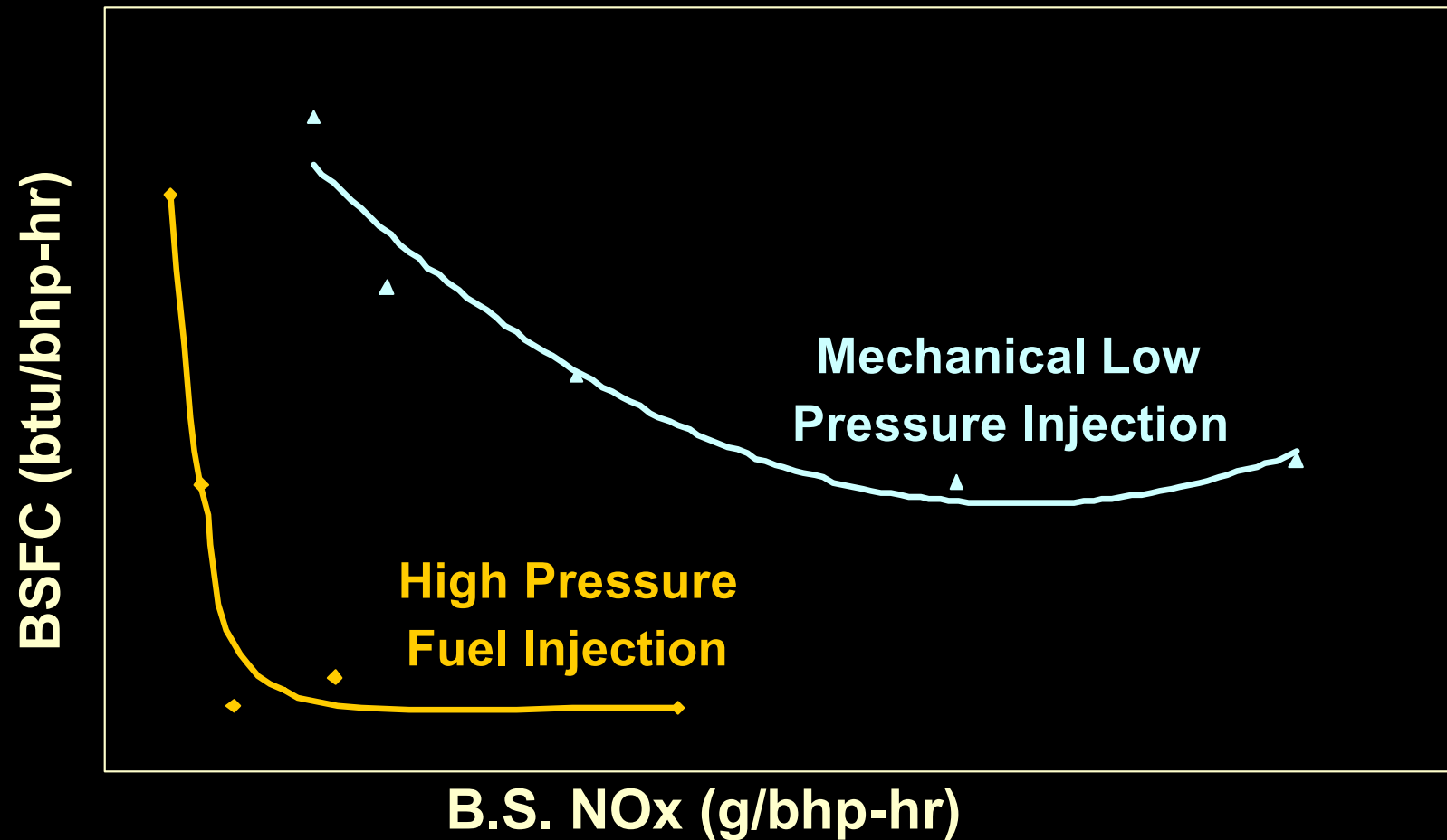
- Fuel injected late in scavenging / early in compression
- Fuel injected at low pressure
- Poor air/fuel mixture,
→ poor combustion
→ increased emissions
- High pressure injection produces dramatic reductions in NO_x & fuel consumption

10

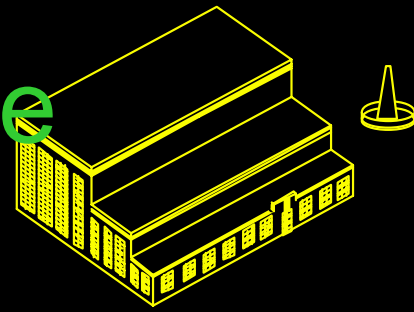
CSU-EECL



Performance Comparison of Low Pressure vs. High Pressure



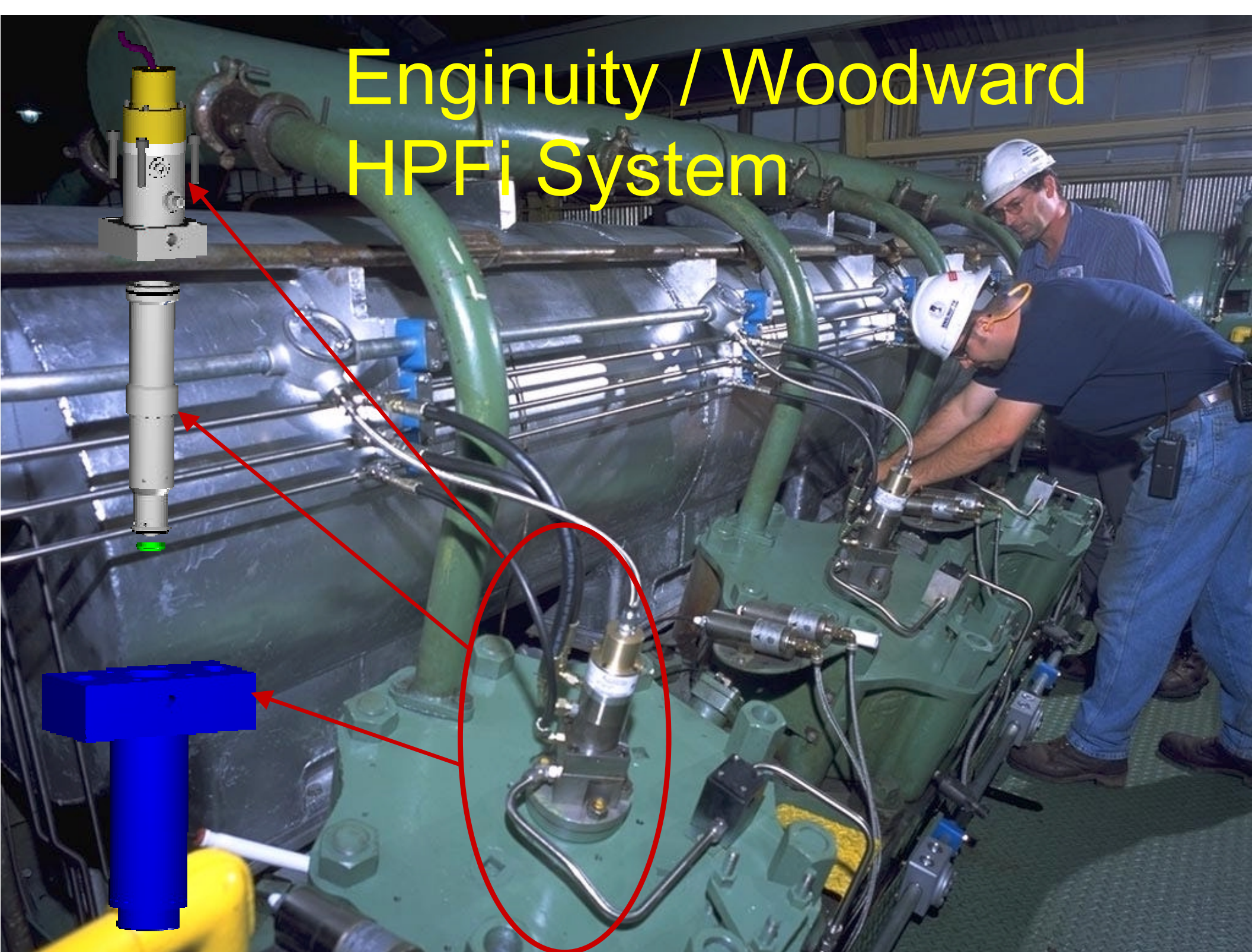
Commercialization of High-Pressure Fuel Injection Technology



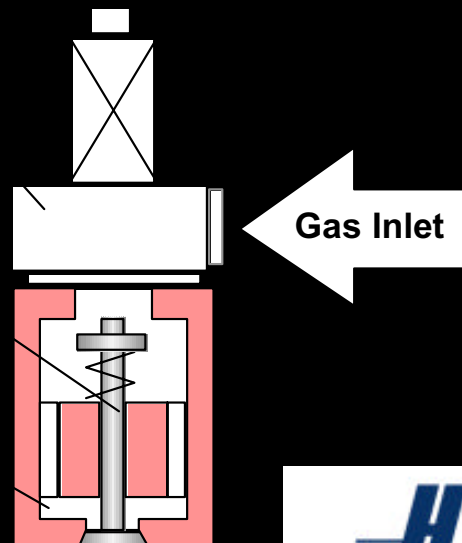
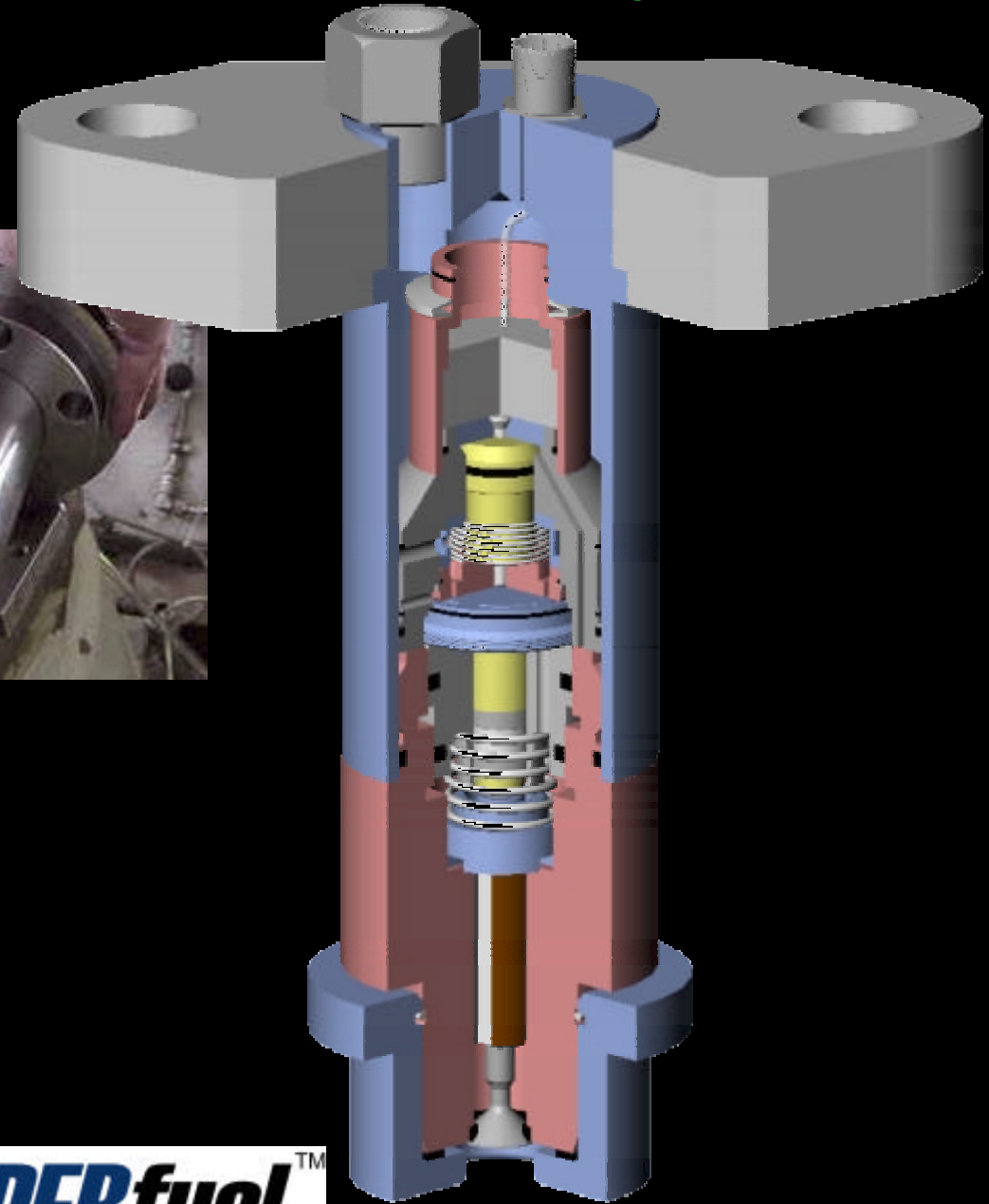
Illustrates focus on rapid technology transfer
& commercial implementation

- Enginuity / Woodward Governor
- Hoerbiger / Altronic
- Louisiana Compressor & Maintenance
- Dresser-Rand

Enginuity / Woodward HPFi System

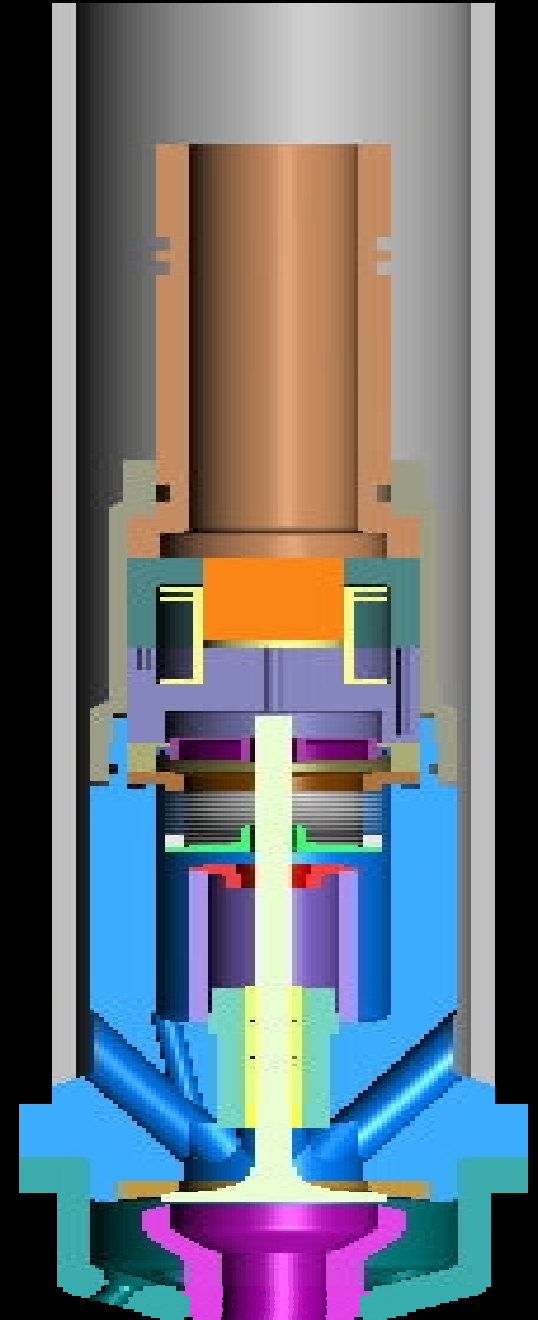
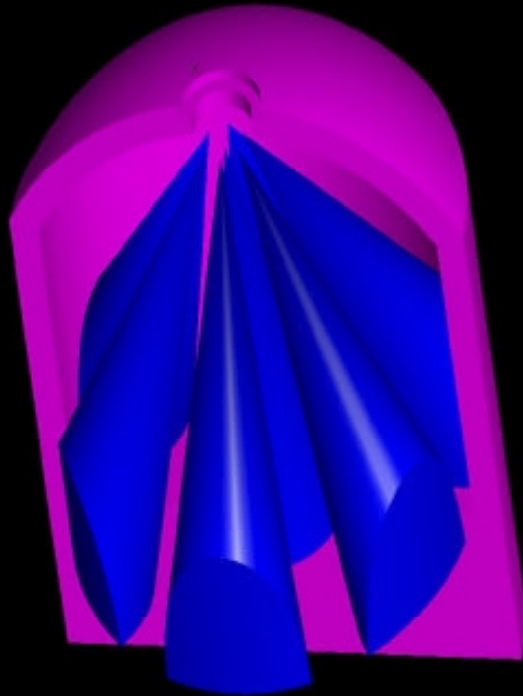
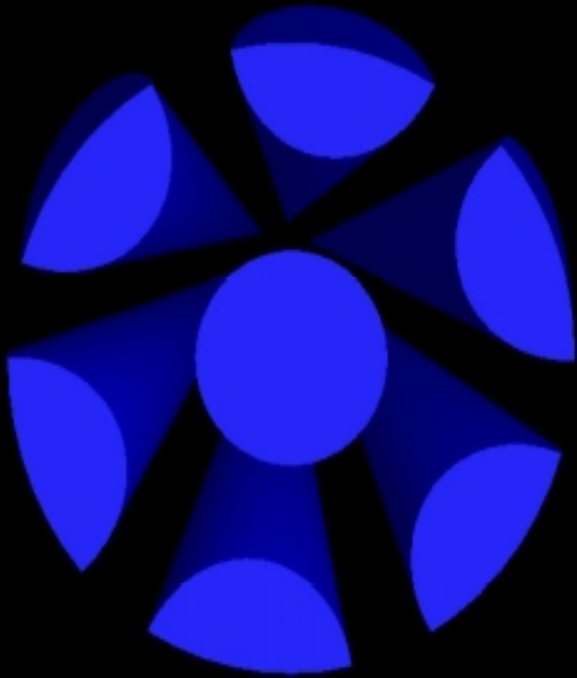


Hoerbiger / Altronic HYPERfuel™ System

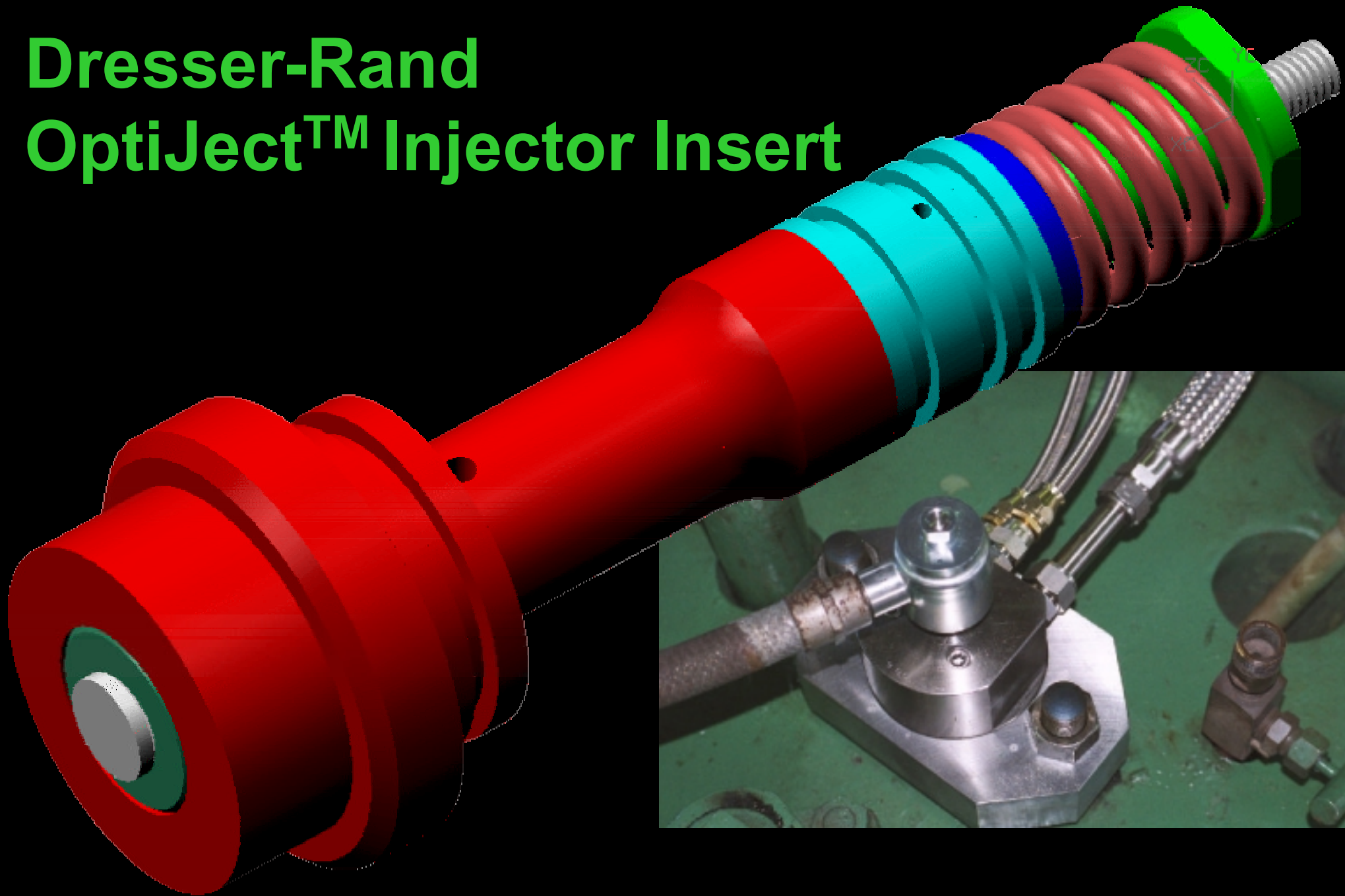


HYPERfuel™
High Pressure Fuel Injection System

LCM Medium Pressure Fuel Injection System

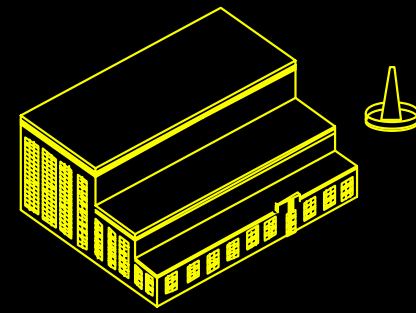


Dresser-Rand OptiJect™ Injector Insert



DRESSER-RAND

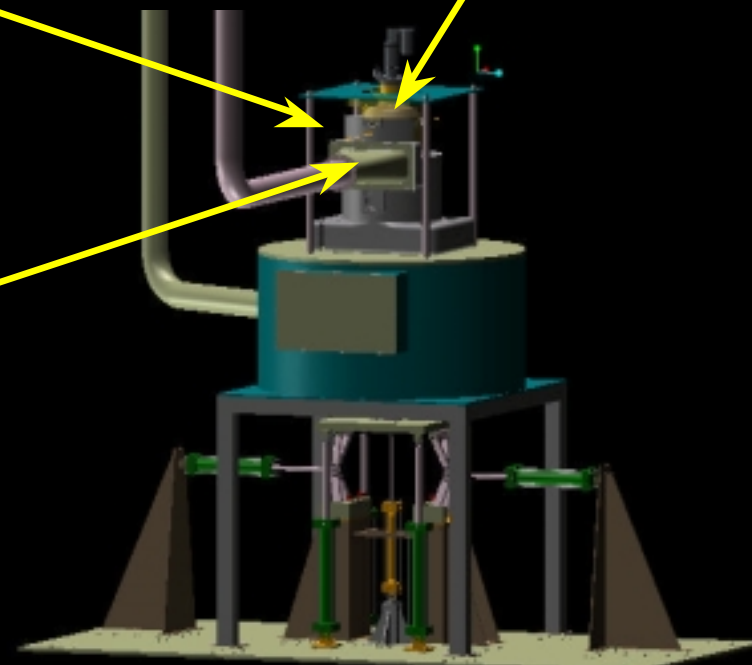
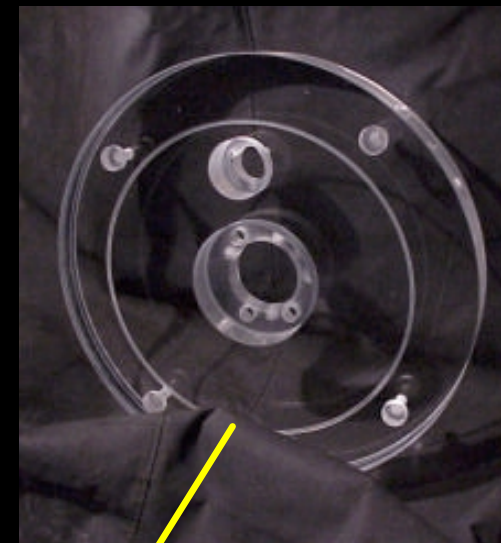
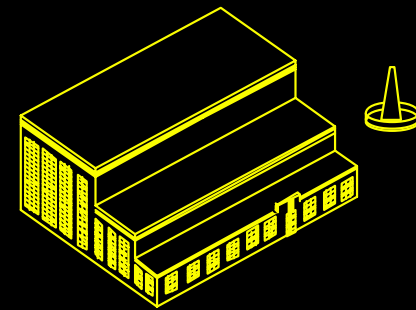
Current Research on Enhanced Mixing



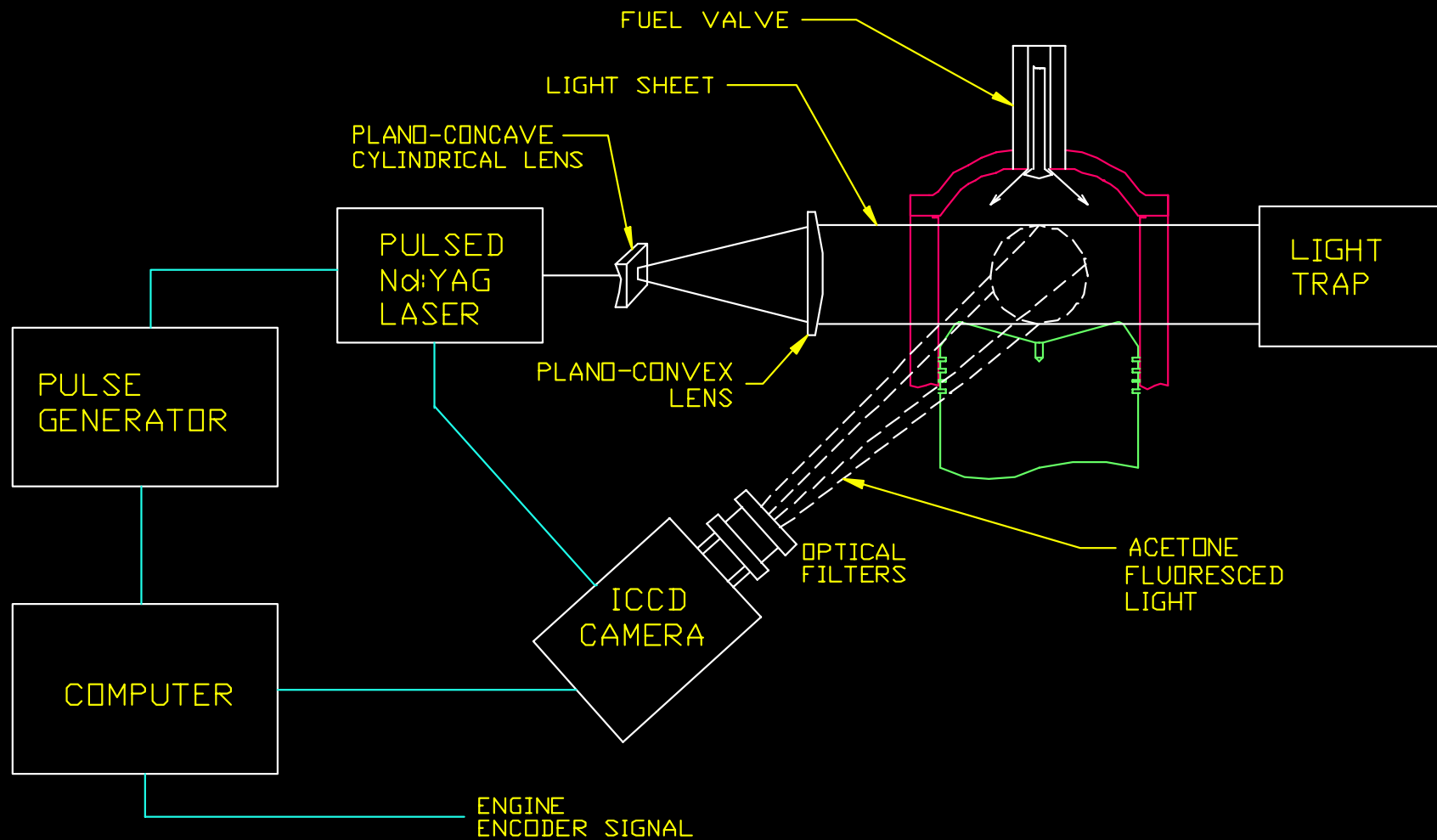
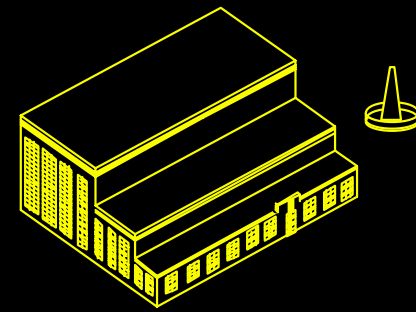
- Experimental studies in optical engine (world's largest) to study mixing & validate CFD models
- Computational fluid dynamics (CFD) to model and optimizing mixing from fuel delivery systems

*Current studies on large bore engines:
significant application to port-injected & single-point medium-speed gas engines*

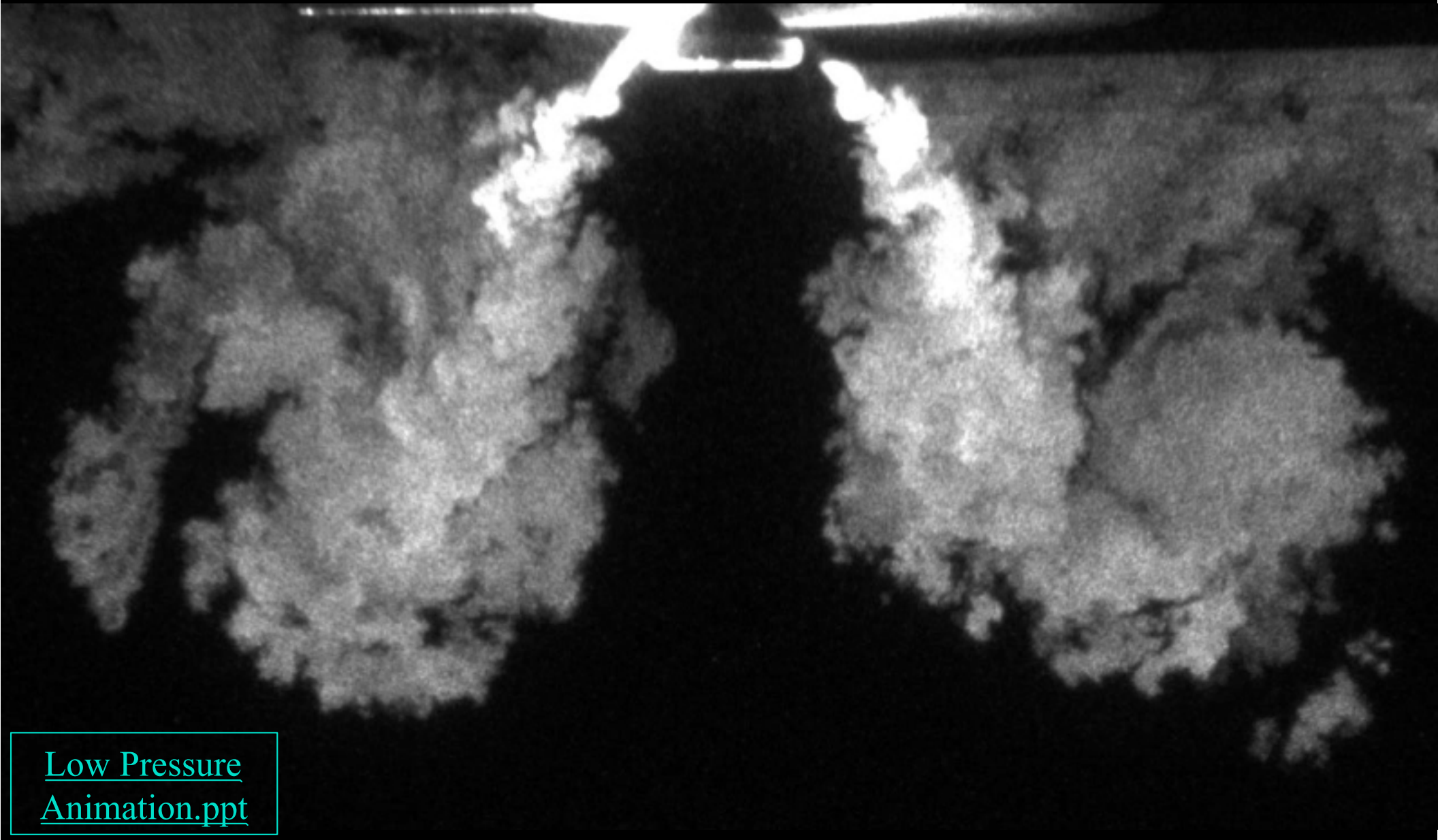
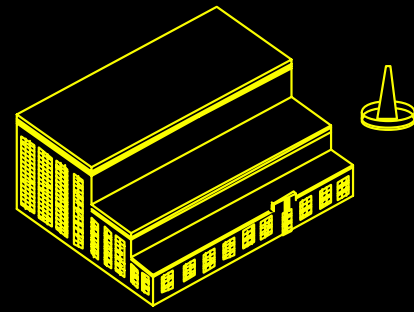
CSU Optical Engine – “World’s Largest”



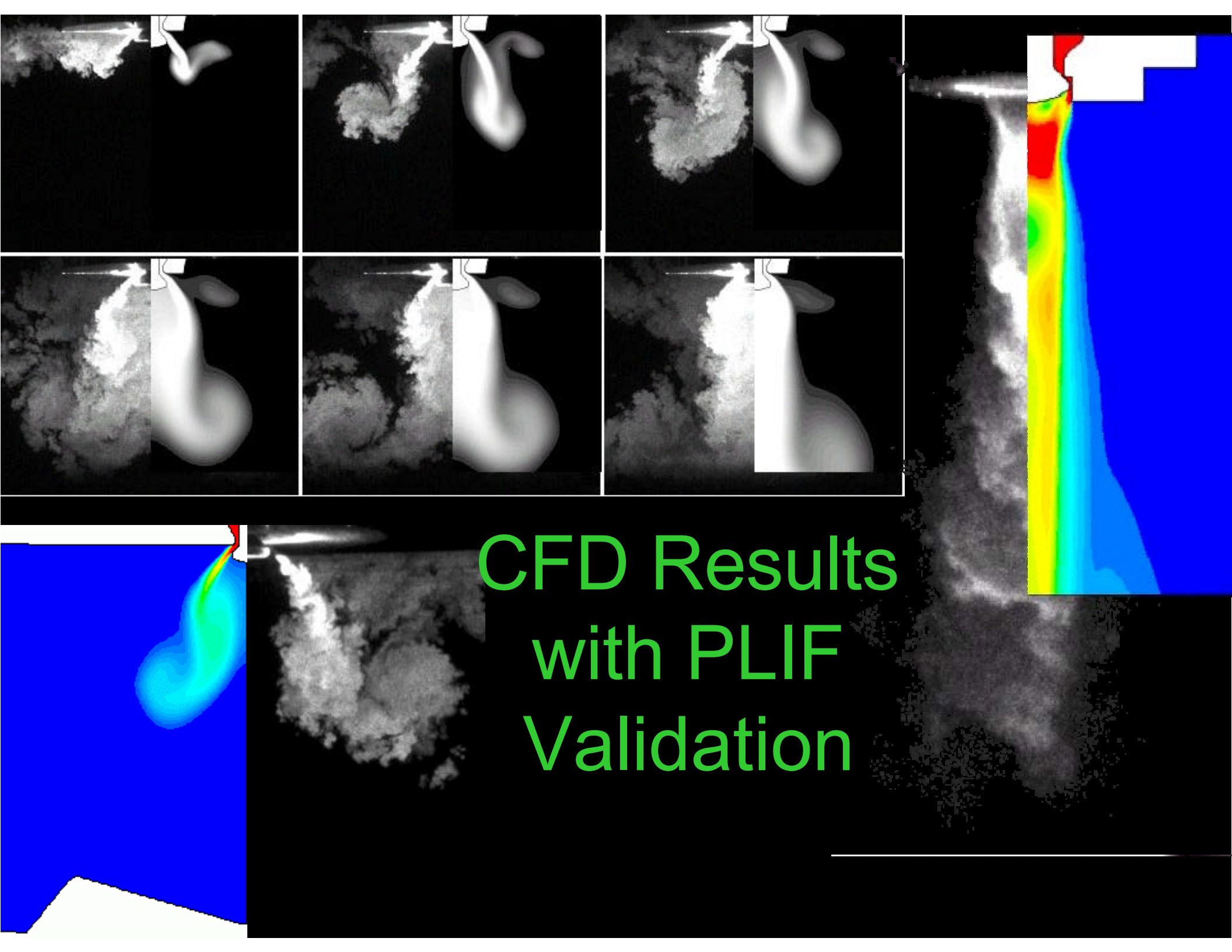
Laser Induced Fluorescence: Basic Test Setup



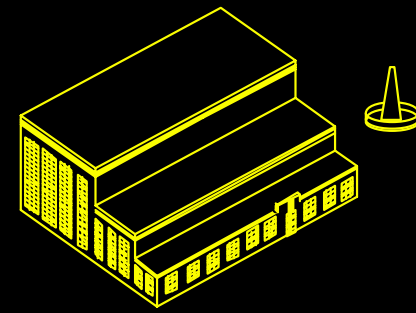
Low Pressure Animation (EGAV)



Low Pressure
Animation.ppt

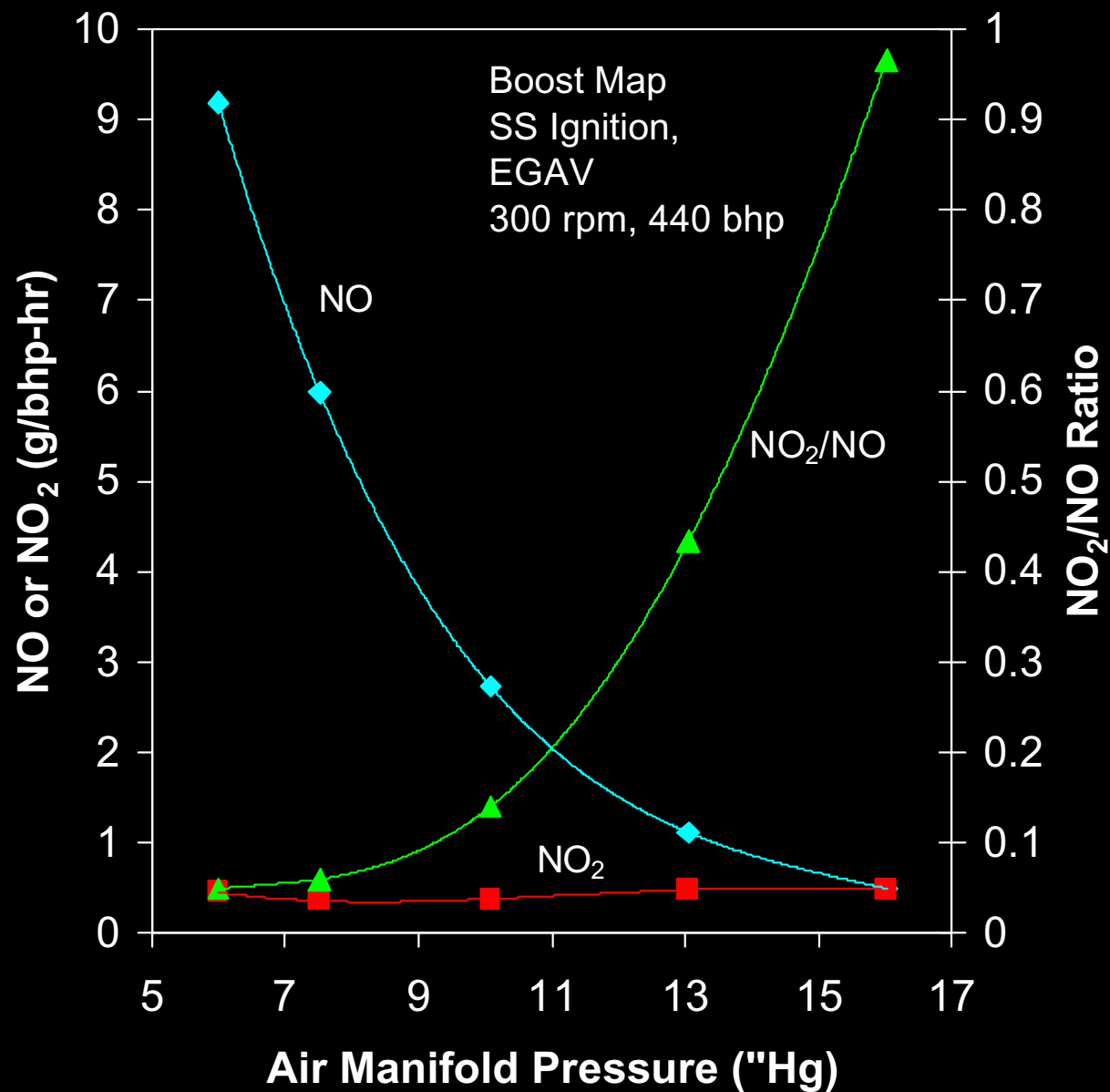
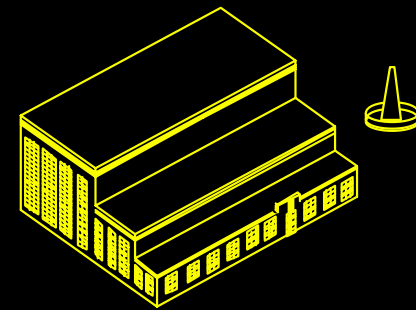


Current Research on Natural Gas Engines

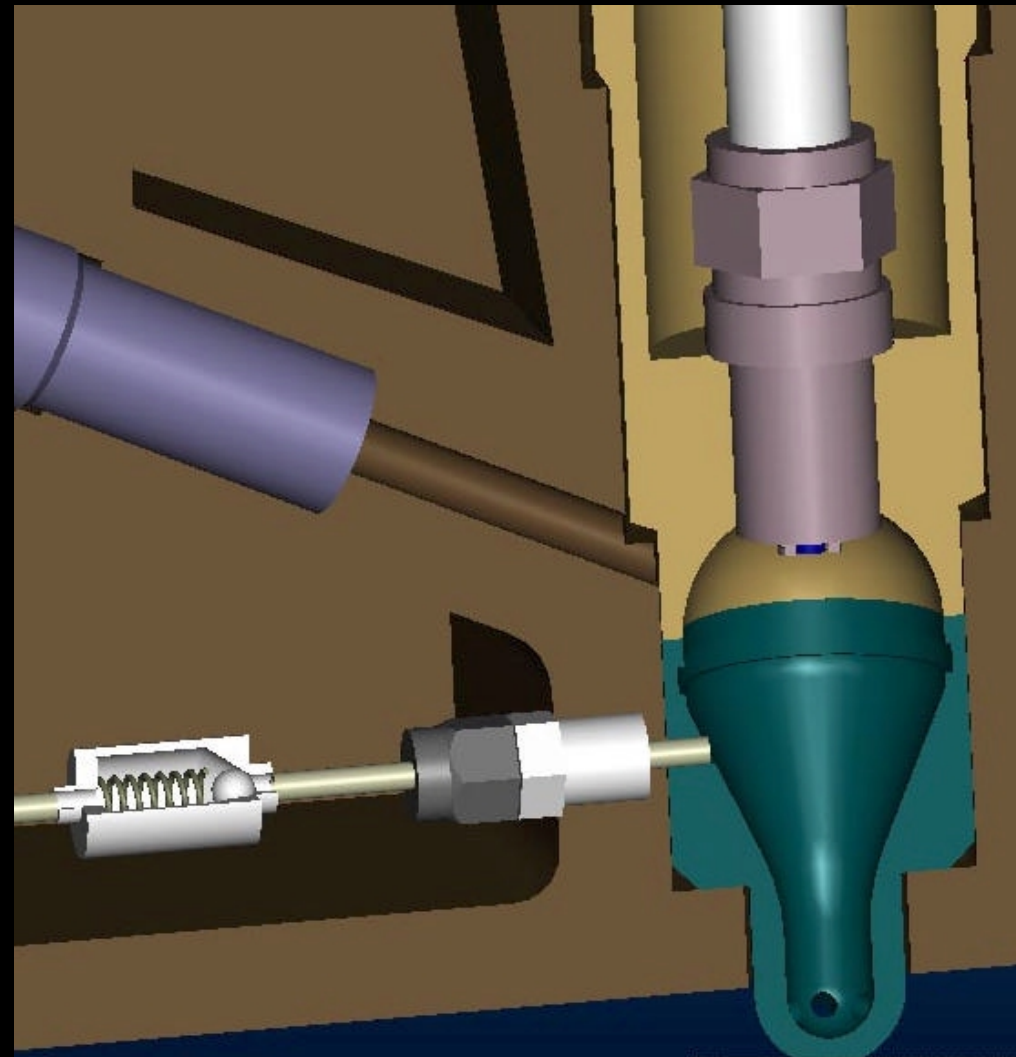
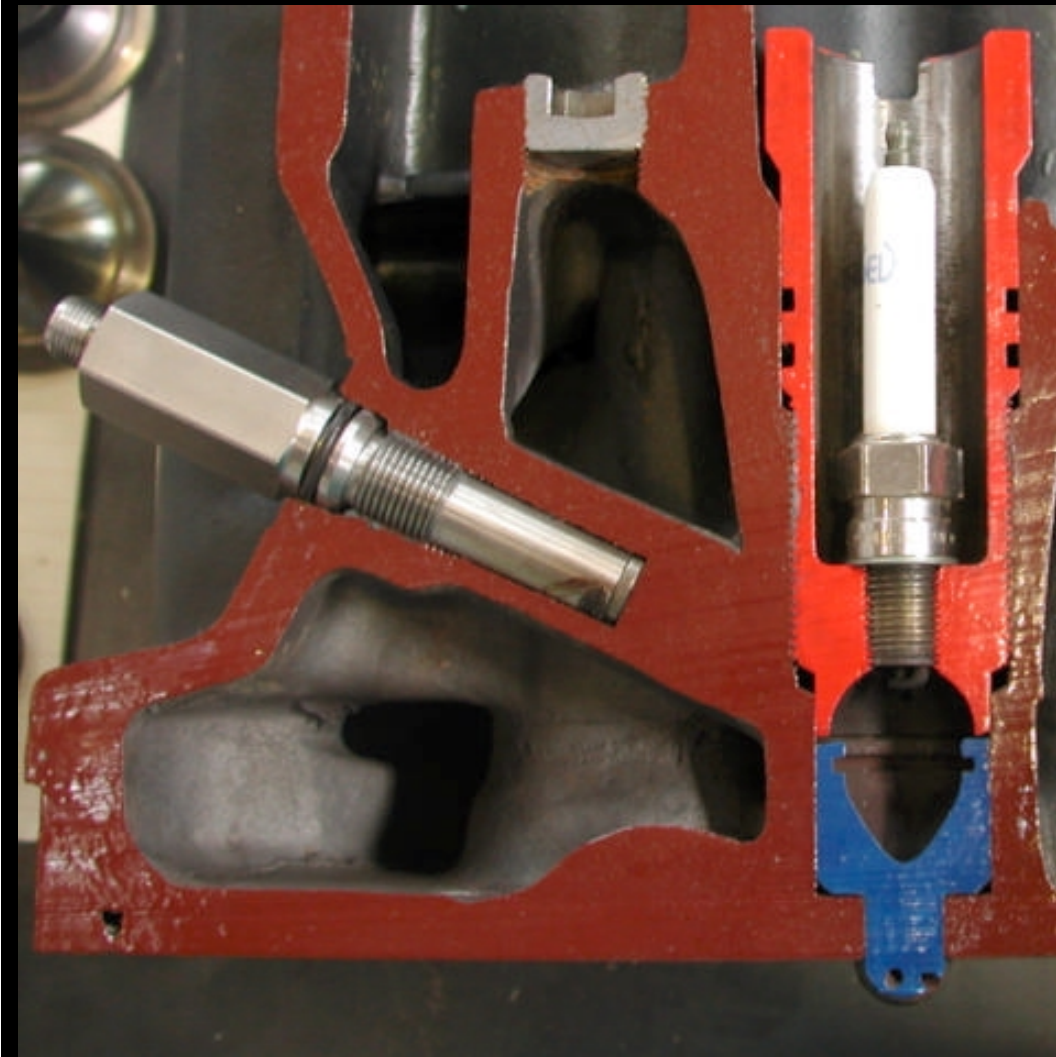
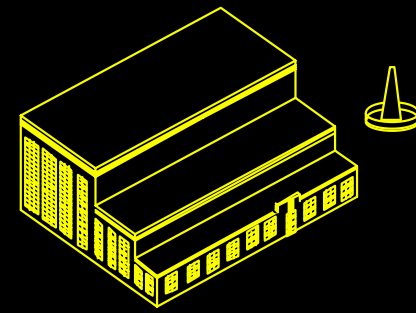


- Low-NOx combustion
- NO₂ formation in low-NOx engines
- Precombustion chamber NOx formation
- Hazardous air pollutants (HAPs)

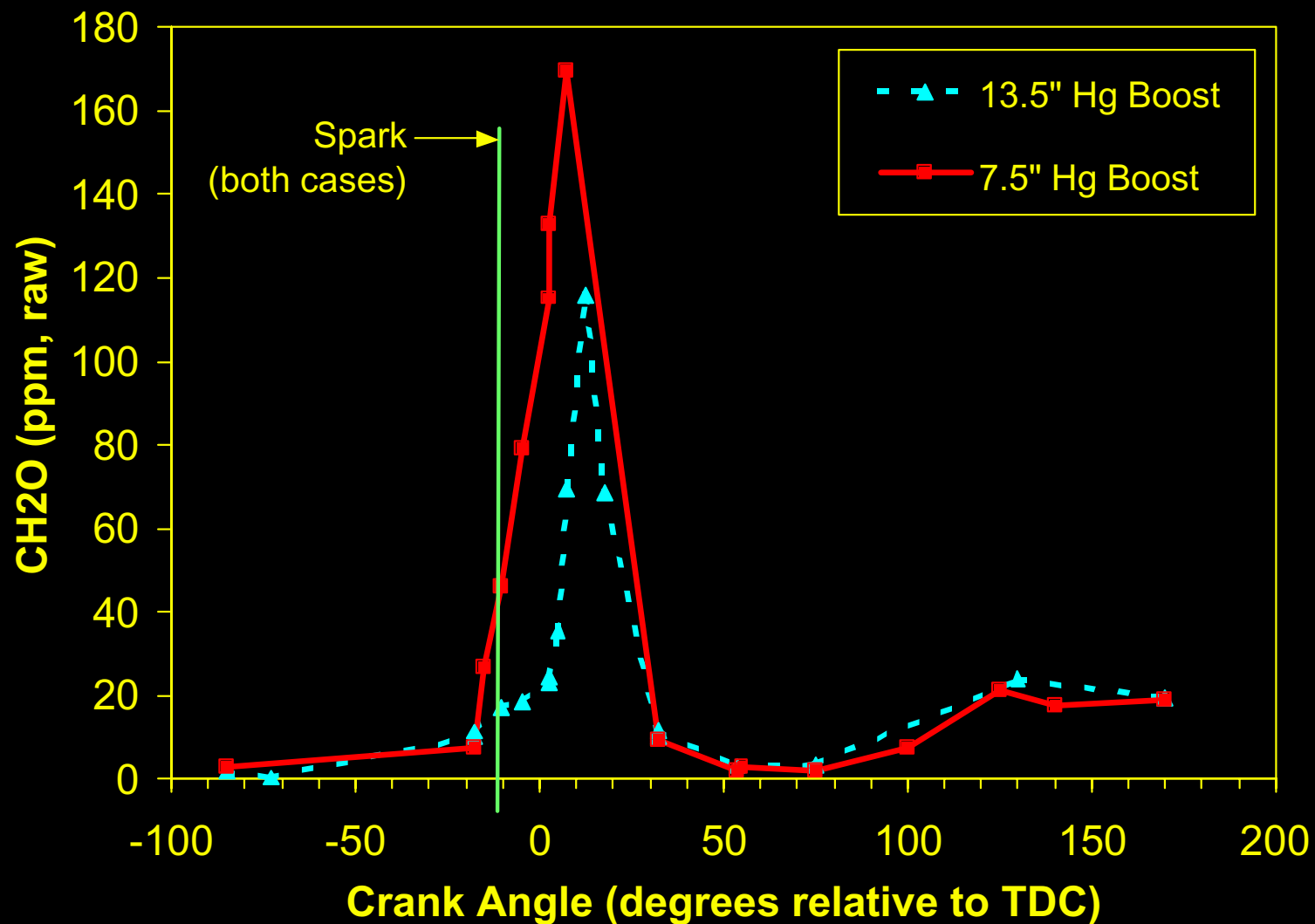
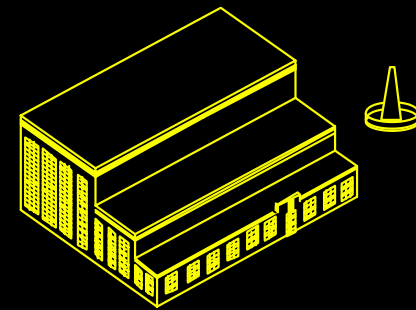
NO vs. NO₂



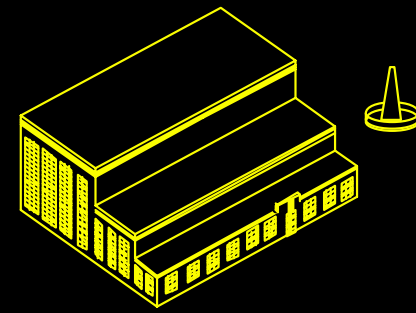
Prechamber NOx Study



HAPs Research: Crank Angle Resolved Formaldehyde Measurements

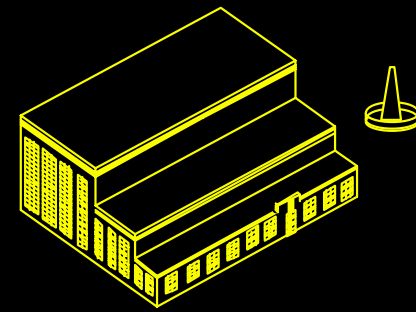


HAPs Research



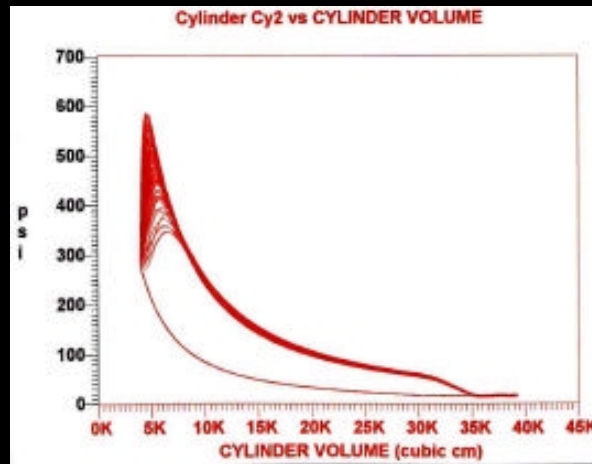
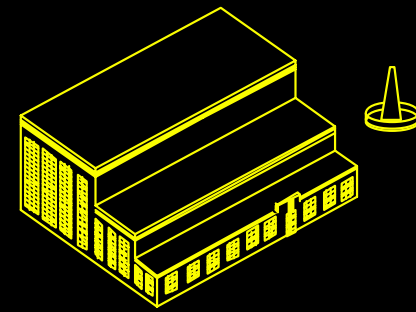
- Formaldehyde formation mechanisms
- Engine studies
- Mitigation studies
- Legislative support to EPA
- Catalyst studies

Ignition Studies

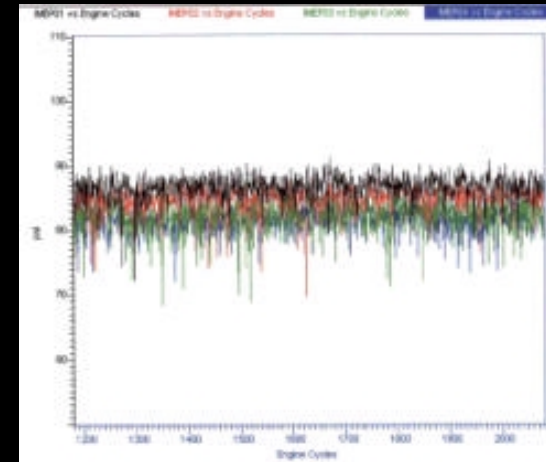


- Conventional ignition systems
- Micro-pilot ignition systems
- Advanced ignition systems

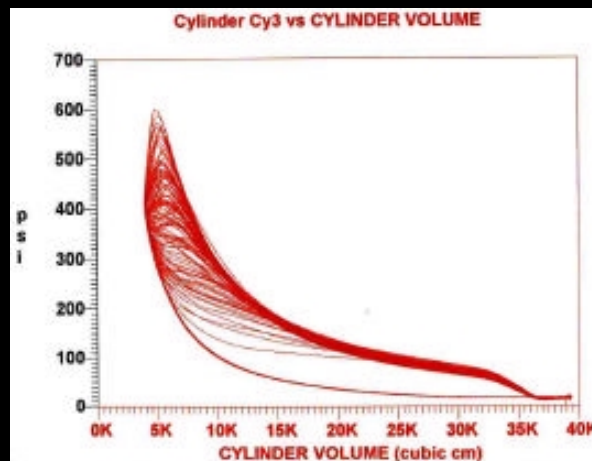
Ignition Studies: Combustion Near Lean Limit



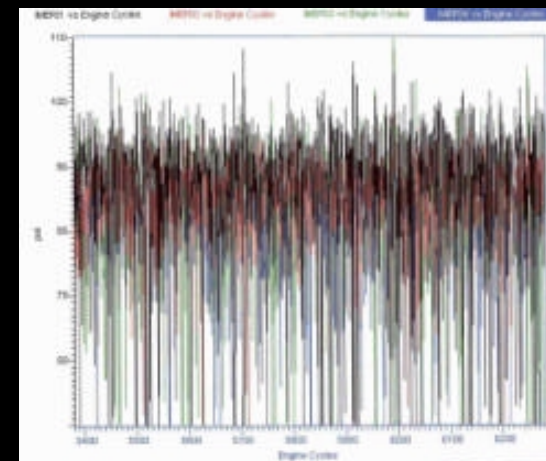
PV Diagrams
Stable Combustion



IMEP
Stable Combustion



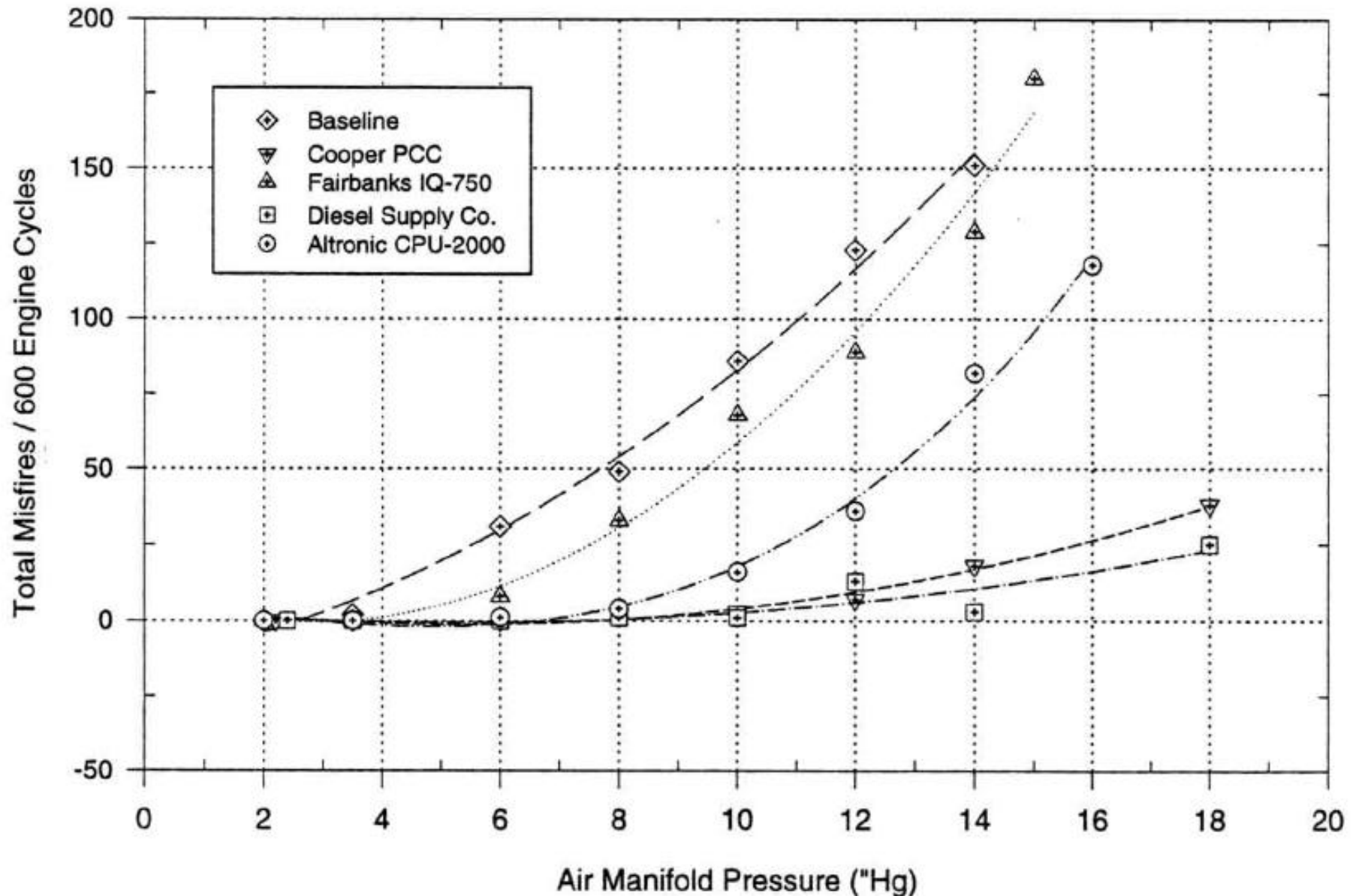
PV Diagrams
Near Lean Limit



IMEP
Near Lean Limit

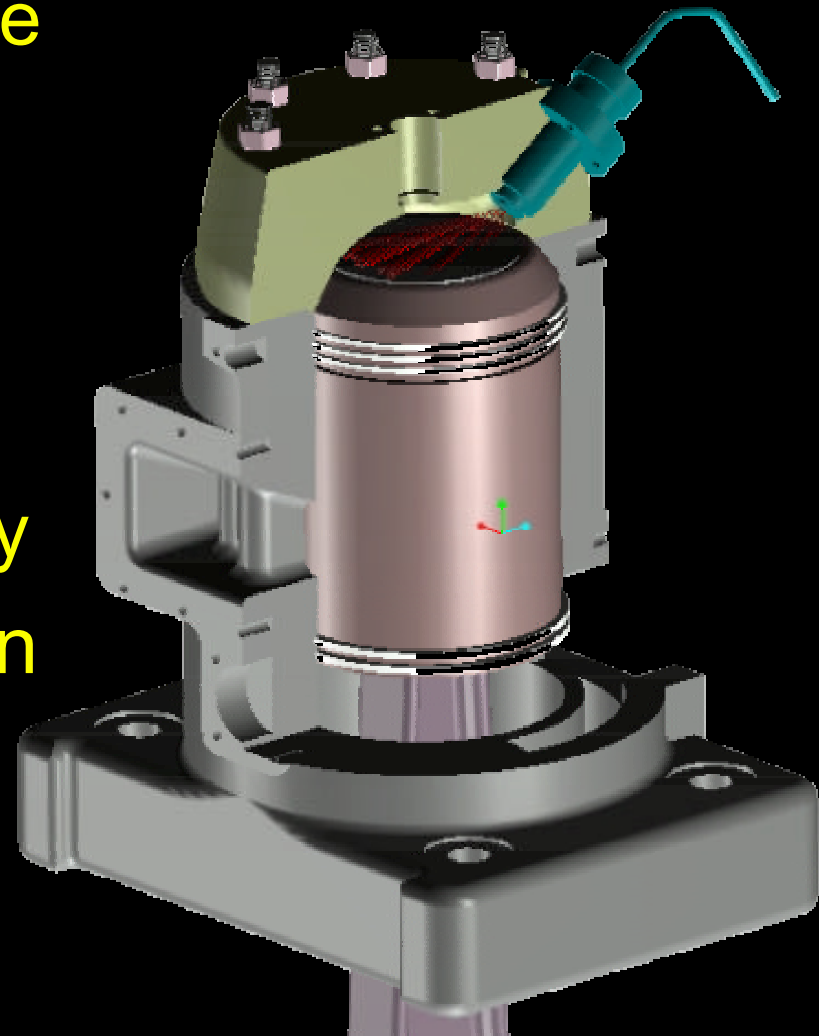
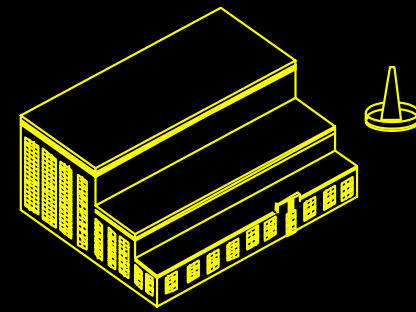
Conventional Ignition Systems

“Great Ignition Shootout”



Micropilot Ignition for Gas Pipeline Engines

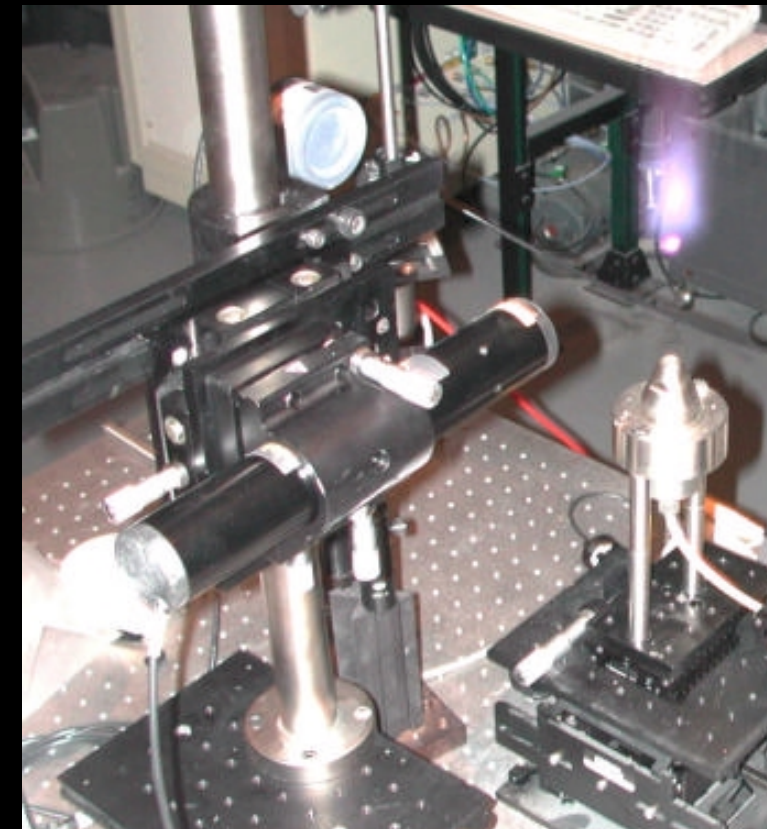
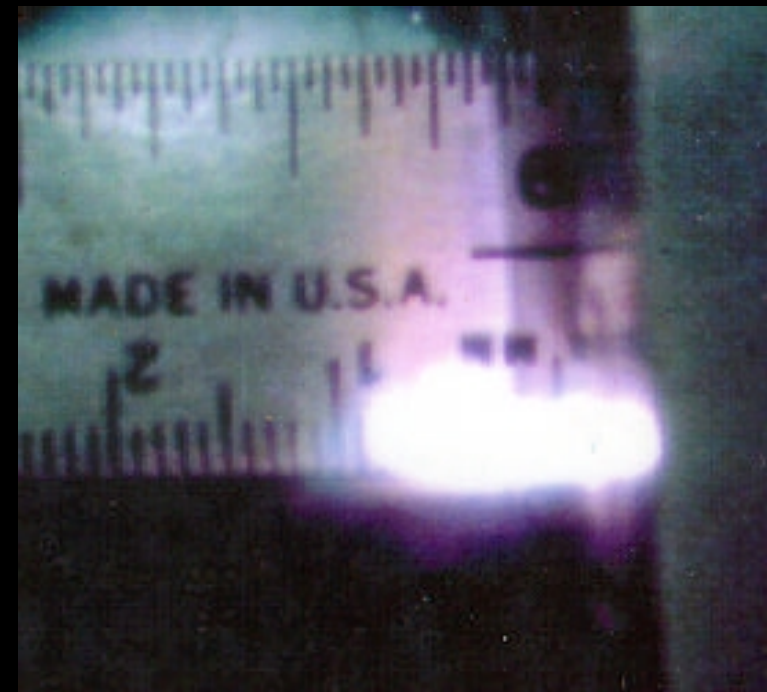
- \$1.7 million project sponsored by:
 - DOE Natural Gas Infrastructure Program
 - Pipeline Research Council International
 - Gas Technology Institute
 - Woodward Governor Company
- Application of micropilot ignition to large bore gas engines
- Ignition quantity less than 1%
- Diesel fuel or crankcase oil



Advanced Ignition Systems

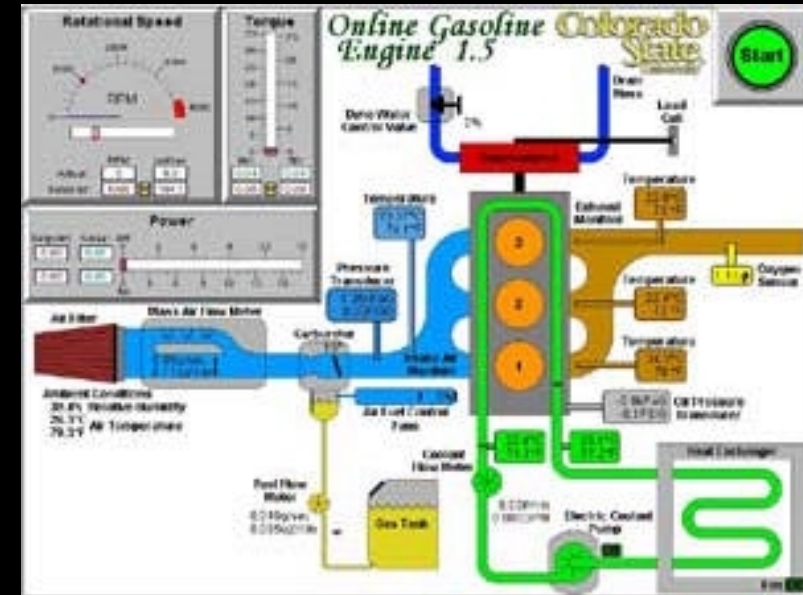
Working with other groups to facilitate advanced ignition technologies:

- Advanced spark / projecting plasma systems
- Laser ignition systems



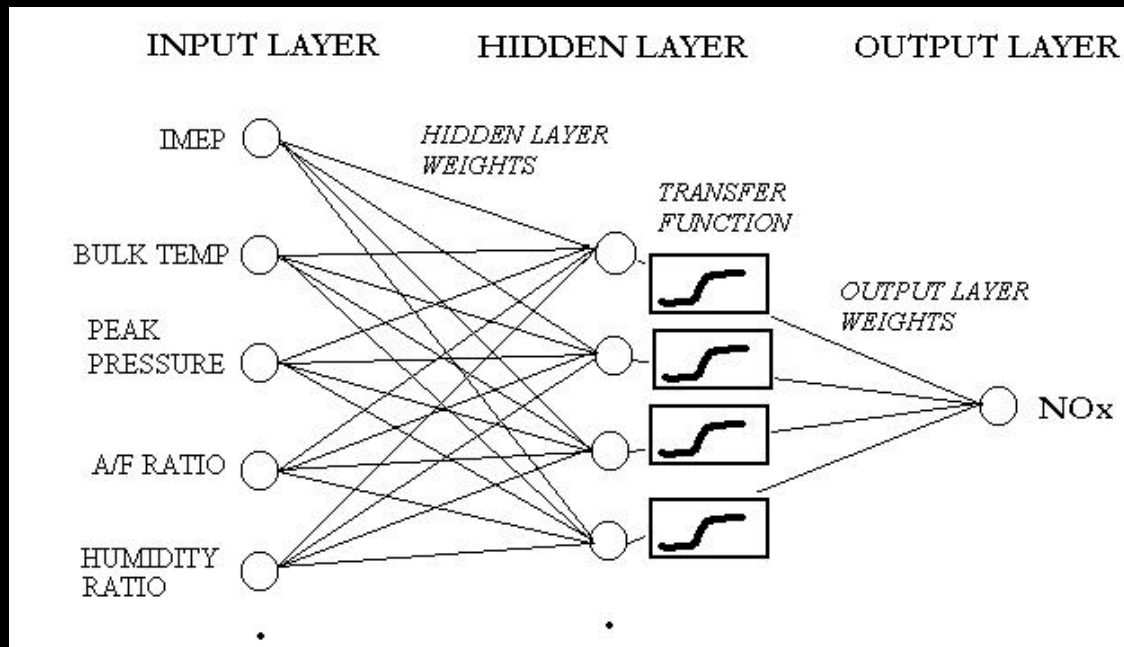
Controls / Sensing / Information Technology

Advanced Neural Network Models for Predictive Emissions Monitoring

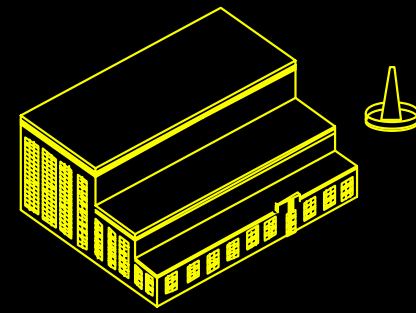


Online Engine:

www.engr.colostate.edu/eecl/

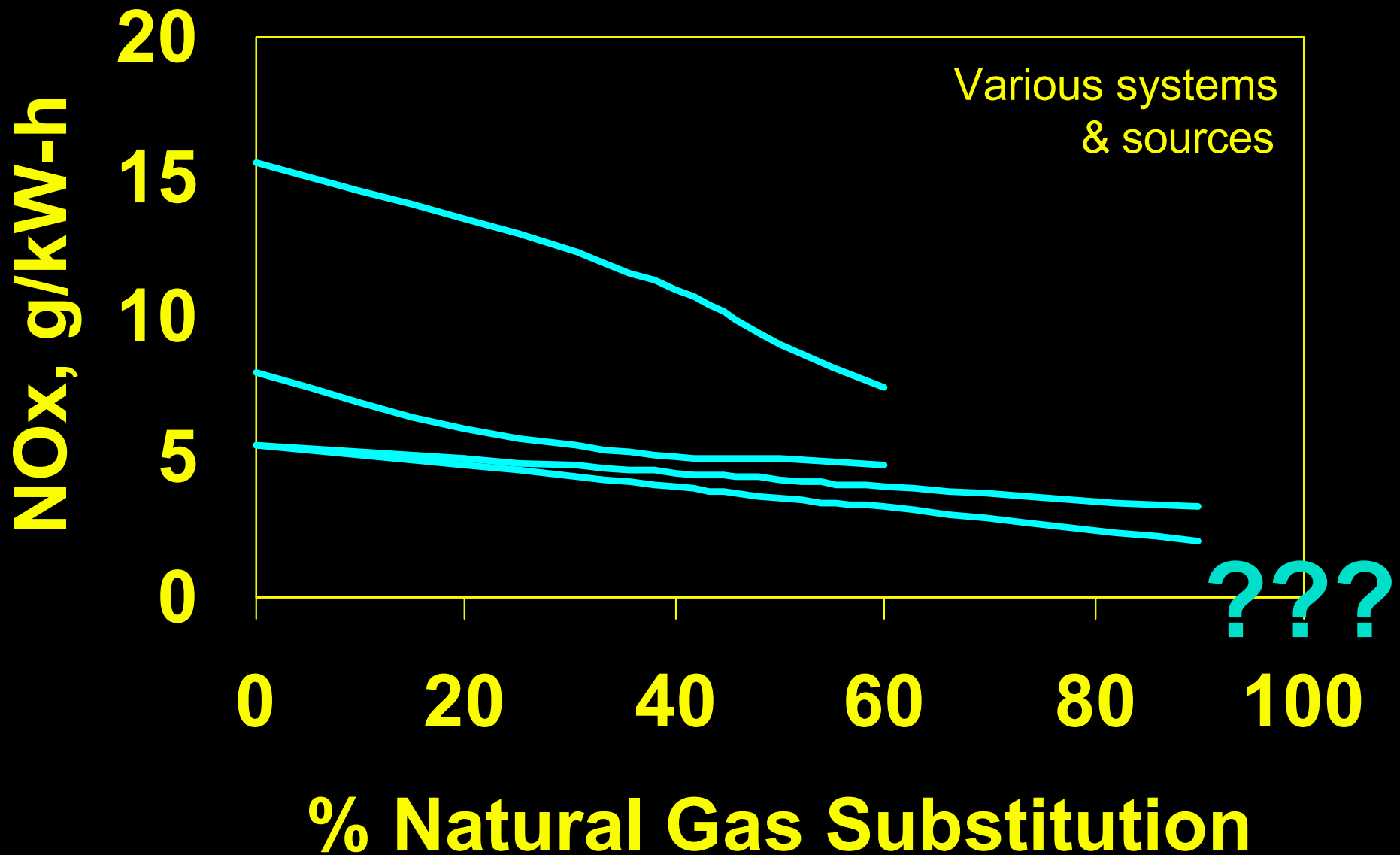
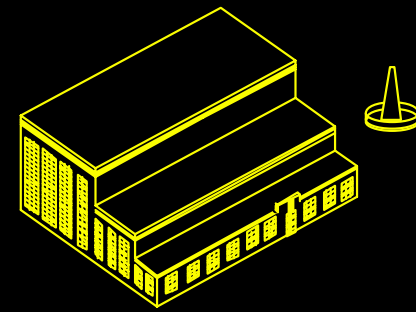


California ARICE Program: Research Needs



- Advanced natural gas engine concepts being pursued through DOE Advanced Natural Gas Reciprocating Engine program
- DOE funding university research on ignition & friction reduction for advanced natural gas engines
- Precompetitive research needed on oxidation catalysts & selective catalytic reduction (SCR) systems for natural gas and diesel engines
- Significant research needs on dual-fuel engine conversions to convert diesel engines to natural gas operation

California ARICE Program Dual-Fuel Emissions



California ARICE Program: Dual-Fuel Engines



- Dedicated dual-fuel systems for new engine installations:
 - Clean Air Partners / Caterpillar
 - Westport / Cummins
- Retrofit dual-fuel systems for existing engines:
 - No widely recognized general conversion systems
- Significant need for:
 - Concept development for high quality electronic dual-fuel systems
 - System validation
 - Demonstration / field studies
 - Certification

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